THERMAL CONDUCTIVITY OF EPOXY COMPOSITES FILLED WITH ALUMINIUM NITRIDE (AlN)

A Thesis Submitted In Partial Fulfilment of the Requirements
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Submitted by

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C E R T I F I C A T E

This is to certify that the work in this thesis entitled THERMAL CONDUCTIVITY OF CERAMIC(AlN) FILLED EPOXY COMPOSITES by ***Swaraj Sourav Nayak*** *has been carried out under my supervision in partial fulfilment of the requirements for the degree of Bachelor of Technology in Mechanical Engineering during session 2014 - 2015 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.*

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

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ABSTRACT

Thermal conductivity of epoxy composites embedded with Aluminium Nitride(AlN) micro-fillers is estimated in the present thesis with analytical modelling. Thermal conductivity of AlN powder filled epoxy composite is calculated by measuring heat flow using an instrument Unitherm TM Model. In the analytical model , a mathematical model is developed to calculate the effective thermal conductivity of the composites filled with particulate fillers with different concentrations. The conductivity values measured experimentally are compared with the analytical ones and experimental ones. These composites with AlN have been fabricated and thermal conductivities of the samples are measured experimentally. Observations can be made that with 15 % of volume AlN in epoxy matrix, thermal conductivity has increased by about 6 times while with25 volume % the thermal conductivity has increased by about 59 times which is much higher than epoxy matrix. A conclusion to draw from the measured values are in close approximation with the proposed model close upto 25 % of vol. fraction at which a sudden rise is observed in the measured value of K_{eff}. This sudden rise in effective thermal conductivity is due to the overlap between filler particle which leads to the formation of conductive chain. The volume percentage after which this phenomenon occur is termed as percolation threshold.

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Chapter 1

INTRODUCTION

INTRODUCTION

In micro-electronic packaging, increasingly important integrate circuit plays role in the electronic and electrical technologies and also is source heat in circuits. The heat must be carried away quickly to avoid any breakage of elements, which requires that the materials used in electronic circuits should have good thermal conductivity besides having good electrical resistivity. These materials used for packaging must have low relative permittivity and low dielectric constant to reduce the heat transfer, which ultimately can provide better device performance.

The heat dissipation in microelectronic packaging which is more complex and integrated is highly required now-a-days. Conventional materials are incapable of giving intended results because low conductivity and high thermal expansion. Under this circumstance special thermal class materials are polymer composites. Polymer composites filled with particulate i.e polymers filled with highly conductive particulate are coming up to cope with such heat transfer issues with a cost effective way.

The imperative elements of the lattice are to exchange directional loads between the strengthening filaments/particles and to protect them from ecological harm though whereas the filaments/fillers in a composite enhances its physical properties, for example, quality, firmness and so forth. A composite is thusly a blend of more than one small scale constituents that vary in physical and chemical form and are insoluble in one another. The primary target is to exploit the predominant characteristics of both materials without trading off on the weak characteristics of either. Consequently in composites, materials are consolidated so as to empower us to improve utilization of their superior properties while diminishing some degree to the impacts of their inadequacies. This procedure of optimization can be advantageous for the imperatives related with the determination and assembling of ordinary materials. Making utilization of harder and lighter materials, with properties that can be mannered to suit specific prerequisites and on account of the strength with which complex shapes can be fabricated, the complete of a built plan regarding composites can frequently prompt both less expensive and better arrangements. The properties of the composites depend essentially on volume fraction and type of fiber and/or molecule embedded in the lattice

1.2: OVERVIEW OF FILLER

Aluminium Nitride (AlN) is a unique ceramic material that combines high thermal conductivity with high electrical resistivity. "Thermal conductivity" is the ability of a material to transfer heat on application of a temperature gradient across its surfaces. In ceramic powder like AlN, heat transfer is through lattice vibrations in micro level. For heat dissipation applications, a high thermal conductive particle is needed to be reinforced with polymer material. The actual thermal conductivity of a material is influenced by factors that reduce the propagation of lattice vibration. Temperature distribution, impurities, particle size and distribution, grain size and orientation all affect the lattice vibrations and therefore thermal conductivity. AlN with an excellent combination of these unique qualities proves itself a desirable material for making composites for micro-electronics applications.

Micro sized Aluminium Nitride powder

FIG1.1

1.3 Types of Composite Materials:

Classifications of composite material is done mainly into three groups on the basis of matrix material use.

1. Metal Matrix Composites (MMC).

2. Ceramic Matrix Composites (CMC).

3. Polymer matrix composite

1.3.1 Metal Matrix Composites (MMC):

These composites are composed of metal or metal alloys reinforced with particulates or fibres. MMC'S offer high strength, stiffness, creep and wear resistance, fatigue and abrasion resistance and fracture toughness. They are stable at high temperature. Aluminium Titanium and magnesium are mostly used as matrix material

1.3.2 Ceramic Matrix Composites (CMC):

CMC'S have ceramic as a matrix material like silicates of calcium and aluminium. CMC'S are characterised by their resistance to high temperature, good corrosion resistance, high melting point, high compressive strength, high modulus of elasticity and low tensile strain.

1.3.3 Polymer Matrix Composites (PMC)

PMC'S are most commonly used composite among all its counterparts. PMC'S finds wide application in industries because of its easy process ability, light weight, resistance to corrosion and desirable mechanical properties. Thermoplastic and thermosets are two main type of polymer.But manufacturing simplicity such as low temperature and low pressure and simpler equipment are required mainly for fabricating polymer matrix composites. Because of this only the development polymer composites are rapid in structural applications.

1.4 Types of Polymer Composites:

Polymer matrix composites are classified into 2 types based on reinforcing material.
They are given as;

1 Fiber reinforced polymer (FRP).

2 Particle reinforced polymer (PRP).

1.4.1 Fiber Reinforced Polymer (FRP)

These are of two following types

1. With discontinuous fibers
2. With continuous fibers

Fiber strengthened composites with reinforcing fillers which have length much more prominent than their cross-sectional measurements. In the event that its properties change with length of fiber it is considered short on the other hand irregular fiber. fibre and framework are for the most part the fundamental constituents of basic stage of fiber strengthened composites. Filaments are the principle wellspring of quality in composite. Principle capacity of fibres is reinforcement keeping in mind framework sticks all the filaments together fit as a fiddle and exchanges stresses among the reinforcing fibres. Among materials epoxy and polyester are mostly utilized. Pitch of the epoxy which has higher holding and less contraction than polyesters tar emerges as advanced choice for its higher expense.

1.4.2 Particle Reinforced Polymer

These composites are composed of particulates embedded in matrix body. Particulate can be in the form of flakes or powder. Concrete and wood particle board are Natural examples of this type. Mainly round, square and triangular shapes of particulate are used. Shape size and volume concentration of particulates have significant effect on overall performance of composite. Particulate composites are strengthened by the hydrostatic coercion of fillers in matrices. Particulate reinforcement in three- dimension in composites causes isotropic properties.

Among all types of composite material polymer matrix composite material reinforced with different type of desired filler material is more frequently used as compare to its other counterpart. Polymer composites have also been widely accepted in various industries.

1.5 Why PMCs are considered:

PMCs have excellent dielectric and chemical properties besides their good process ability and low fabrication cost , which is beneficial to its application in electronic packaging applications. But in previous studies, it can be seen that the effective thermal conductivity possible in PMCs are not high. Therefore, a technological improvement has been achieved that conceived the fabrication of PMCs with quite improvement in effective thermal conductivities, without comprise with electrical insulating property of polymer. One of the methods of improving the effective themal conductivity of PMCs in addition of strengthening filler in the polymer matrix. Polymer composites embedded with metal /fibre particulates has now become important for many fields .

1.6 Application of composite in various fields:

Polymer composite finds their application in various fields. Based on the requirements like cost, thermal properties, durability, corrosion resistance properties etc different filler materials are added into polymer matrix. Epoxy polymer composite is perhaps the one of the most widely used polymer composite. Epoxy polymer composite provides high strength to weight ratio because of low density of epoxy resin. Because of this property it is used in space industries. One of the most important uses of epoxy polymer composite is in electronic devices. There are various applications of polymer composite in different fields. In polymer composites polymers utilized are epoxy. The gatherings has particular qualities and advantages over different polymers; consequently application is taking into account necessity. The choice is satisfied by properties like minimal effort, ease in planning and generation of useful parts and so forth. By utilizing of reinforcements in polyester has kept on being utilized as a part of enhancing the framework and different applications.

IN MICRO-ELECTRONIC PACKAGING

Application of integrated circuits are dramatically increasing now-a-days. Uses of polymer material to fabricate this type of circuit boards are very important not only for structural point of view but also for heat transfer perception. Therefore superior materials are required for packaging and encapsulation micro-electronics applications. But due to compact space inside the circuit heat dissipation has been the major problem in microelectronic applications. Mostly epoxy or polyester are used in heat sink applications but there is a drawback of having low thermal conductivity. But at the same time, there will be at drop in their electrical resistivity and also there is possibility of rise in their dielectric constants. For this reason ceramic powders are preferred over metal powders.

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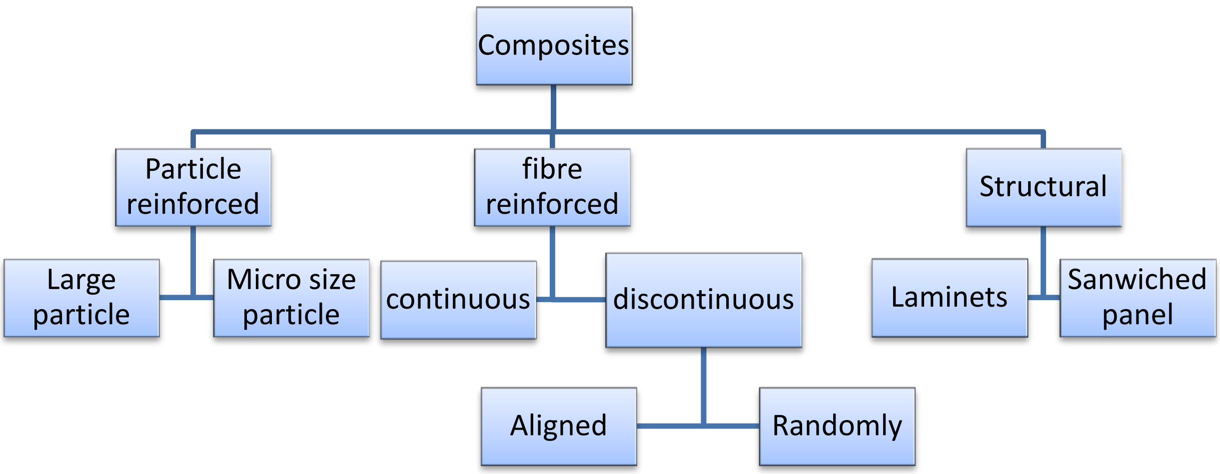

Classification of composite : FIG 1.2

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Chapter 2
LITERATURE REVIEW

LITERATURE SURVEY

The aim of the literature review is to provide experimented informations on the Application specifically to be considered in this thesis and to give importance to the relevance of the present method and model development. Brief reviews inside this thesis on:

1. Particulate Filled polymer composites.

2. Thermal Conductivity of Polymer composites.

3. Thermal conductivity model

2.1 On particulate filled polymer composites:

Particulate fillers with high hardness comprising of clay and fiber particulates made of glass are broadly being utilized nowadays to drastically improve the mechanically properties, for example, wear resistance, at about 3 times higher than previous ones [5]. In such manner, Yamamoto et al. [6] experimented that the state of silica molecule have huge consequences for the mechanical properties, for example, weakness resistance, cracking properties. Nakamura et al. [7] talked about the impacts of size and state of silica particles on the quality and crack strength taking into account molecule network attachment furthermore discovered an increment in the flexural and rigidity as particular surface area of particles is expanded. Geon-Woong Lee et al. has reported to achieve high packing fraction to build a heat flow path without formation of conductive chain path [8]. Srivastava and Shembekar studied the fracture properties of epoxy resin and it is observed that there is an drastic improvement in toughness by inclusion of fly ash particles as filler material[9]. The particulates filler also have influence on the mechanical properties according to their characteristics of packing. The maximum packing and volume fraction of filler shows the size distribution of the particles embedded in the matrix [10-11]. Tavmen did experiments on thermal conductivity of particulate filled polymer composite[12].

2.2 On Thermal Conductivity of Polymer composites:

Reports are accessible in the current writing on trial also as logical and numerical studies on thermal conductivity of particulate filled polymer composites [13]. The fillers most as often as possible utilized are some common metal particles used in thermal application, short carbon fiber and particles and graphite. Complete investigation on modelling and strategies for foreseeing the thermal conductivity of polymer composites was initially introduced by Progelhof et. al [14-15].Nielsen model was utilized by Procter and Solc [16] as an expectation to research the thermal conductivity of a few sorts of polymer composites loaded with diverse fillers and affirmed its usability. Nagai [17] found that models using for Al2O3/epoxy framework and a changed manifestation of model for AlN/epoxy framework are both good predictable hypotheses for heat conductivity. Griesinger et. al [18] reported that low density poly-ethylene has its thermal conductivity expanded from 0.55 W/mK for anisotropic example, to the estimation of 55 W/mK for a specimen with an introduction proportion of fifty. Polymer materials filled with ceramic powder finds their application in microelectronic since ceramic have high thermal conductivity and low electrical conductivity (electrical insulator).Above literature suggests that addition of ceramic powder as filler considerably increase the thermal conductivity of composite without any significant increase in electrical properties of composite[19]. Additions of multiple fillers have also been practised in order to improve thermal conductivity of multi filler filled composite. Apart from experimental studies, numerical method has also been used to calculate the thermal properties of polymer composite [20]. Veyret et al. [21] resorted to numerical method to determine the thermal conductivity of polymer composite.

2.3 On thermal conductivity model :

Analytical model development has been carried out previously to determine the effective thermal conductivities of polymer composite filled with ceramic particulates. The fillers are assumed to be spherical in shape embedded in cubic matrix which forms a series or paralle arrangements thermal resistors taking along heat flow direction.

For the parallel conduction model:

$$k_{eff} = (1-\phi_f)k_p + \phi_f k_f$$

For series conduction model

$$1/k_{eff} = (1-\phi_f)/k_p + \phi_f/k_f$$

The above two correlations is derived from the theory of RULE OF MIXURE (ROM) . Different fractions are taken to finalize the rules driving the thermal circuit of analytical models.

$$\text{Log}\,(k_c) = \emptyset * C_2 * \log\,(k_f) + (1-\emptyset)\log\,(C_1\ k_m)$$

Where, C1, C2 are constants determined from experiment. This experimental model seems to be appropriate for the experimental data quite in a manner. However determination of the proper constants,exact experimental datas are needed. An equition for spheres for a homogeneous.

$$1-\phi = \left[\frac{k_c - k_f}{k_m - k_f}\right]\left(\frac{k_m}{k_c}\right)^{1/3}$$

Based on a proposed theoretical model considering distribution of particles the as well as their volume fraction in the matrix in previous experiments. According to Brugger , expression for calculating effective thermal conductivity is :

$$\frac{1}{\frac{1}{Kp} - \frac{1}{Kp}\left(\frac{6\emptyset f}{\pi}\right)^{\frac{1}{3}} + \frac{4}{Kp\left(\frac{4\pi}{3\emptyset f}\right)^{\frac{2}{3}} + \left(\frac{2\emptyset f}{9\pi}\right)^{\frac{1}{3}}(Kf - Kp)}}$$

Objective of the present Investigation

The objectives of this work are given as follows:

1. Fabrication of composites with considerable cost filled with Aluminium nitride powder as the filler used for reinforcement with an aim of present work to improve the thermal properties of epoxy polymer composite.

2. To fabricate the boron nitride filled epoxy composite with two different concentrations by hand lay-out technique.

3. Calculation of effective thermal conductivity (Keff) of these polymer composites obtained experimentally.

4. To study the effect of incorporation of micro sized boron nitride on the heat conductivity of epoxy.

5. To validate the theoretical model by comparing the results with measured values.

6. To identify the potential applications of these composite in microelectronics.

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Chapter 3

MATERIALS AND METHODS

MATERIALS AND METHODOLOGY

Metals, ceramics and polymers are most often used as matrix material for processing of composite. Most commonly used matrix material is polymer matrix since polymers are cheaper, easy to fabricate into complex part with less tooling cost, show excellent properties at room temperature as compare to ceramic and metal matrix. Polymer matrix can be of two type viz. Thermoplastic and thermoset. Due to huge 3D cross link structure thermosets show good electrical insulation properties, outstanding thermal stability and better creep resistance. Epoxy, polyester, vinyl ester and phenolic resin are example of thermosets which are most commonly used. Perhaps epoxy is the one of the most commonly used thermoset resin. Epoxy is used for packaging material since it has low density (1.2 gm. /cc), excellent processability, low dielectric constant, very good electrical insulators (and hence defend electrical components from short circuiting) and low cost. Keeping all above benefits in mind, for present model epoxy has been selected as matrix material. Some common properties of epoxy resin in tabulated below.

3.1 Analytical model analysis :

In analytical model, a cubical model of matrix material filled with reinforcement particulates is considered. The arrangement of thermal conductive sphere with various volume concentrations is assumed to be a network of thermal resistance consists of thermal resistors connected in series/parallel along the heat flow direction. The layer within the matrix which have no particulate filling and considering thermal contact resistance (R_{int}) in the model

$$R_{total} = R_{int} + \Sigma R_i$$

According to Fourier 's law of heat transfer , the heat flow rate across the element is

$$Q = K_{eff} \times a^2 \times \Delta T/a = K_{eff} \times a \times \Delta T$$

where K_{eff}= effective conductivity of the composite

a= side of the matrix cube

and the resistance of element is = $R_{total} = 1/ K_{eff} \times a$

Considering thin layer of the spherical filler with thickness dy as long upward direction .

Q_{total}=Q_m + Q_f

Q_m and K_m= heat transfer and conductivity of matrix material

Q_f and K_f = heat transfer and conductivity of filler material

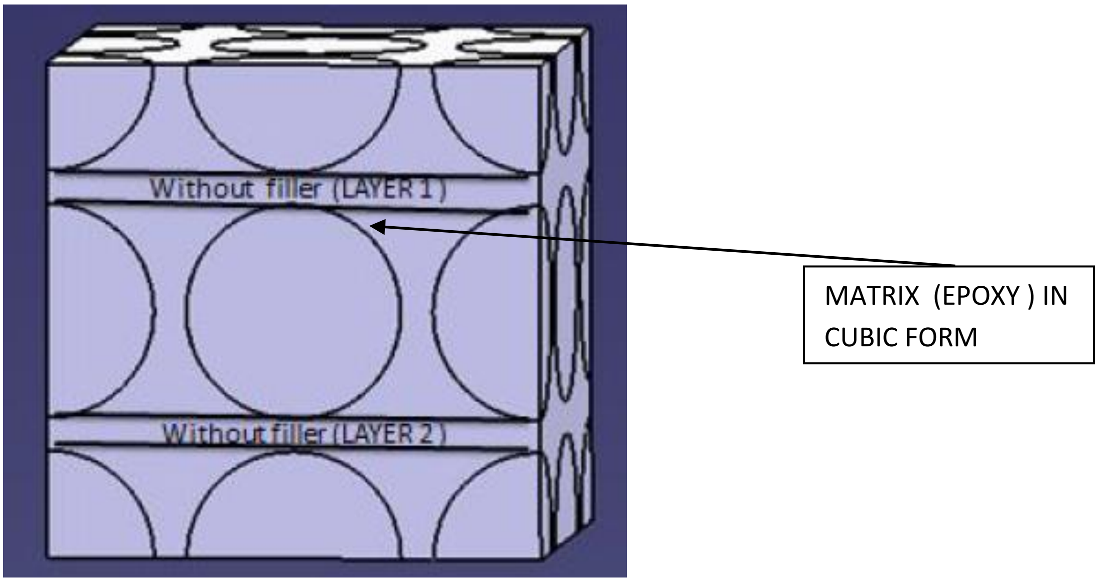
Let side length of the matrix cube and particle radius is a & r respectively.

$Ø_f$= volume fraction = $(4/3\ \pi r^3 \times 4)/a^3$

CASE 1:

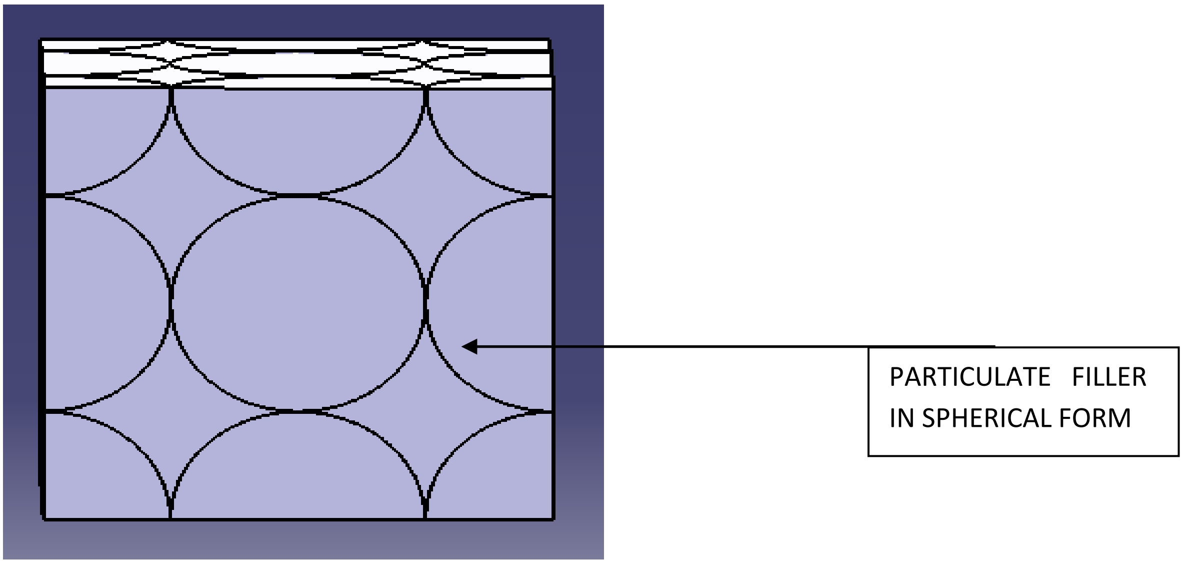
Here particulates are arranged, such that there is gap between the layers means there is a layer of matrix without particulate layer.

Here a > 4r , so volume fraction is less than 26.18 %



CASE 1

FIG 3.1



CASE 2 **FIG 3.2**

CALCULATION OF R_{total} :

For CASE 1-:

There are 6 layers in this model. So resistances involved in these layers are

$$R_1=R_2=R_4=R_6= \frac{1}{2\pi(Kf-Km)} \times \int_0^r \frac{1}{u^2-y^2}\, dy$$

$$= \frac{1}{2\pi(Kf-Km)} \times \left[\frac{1}{2u} \times \log\left|\frac{u+y}{u-y}\right|\right]$$

$$R_2=R_5= \frac{a-4r}{2kma^2}$$

$$\text{where } \quad u = \sqrt{\frac{Km \times a^2}{2\pi(Kf-Km)} + r^2}$$

So $R_{total} = R_{int} + R_1+R_2+R_3+R_4+R_5+R_6$

$$= \mathbf{R_{int}} + \frac{1}{2\pi(Kf-Km)} \times \left[\frac{1}{2u} \times \log\left|\frac{u+r}{u-r}\right|\right] + \frac{a-4r}{2kma^2}$$

For CASE 2 -:

In this case , particulates are arranged in such a manner , so that there is no gap between the layers of the matrix .

Here the a=4r , so volume fraction is equal to 26.18 %
In this model there are only 4 layers instead of 6 as in previous case.

$$R_{total}= R_{int}+ R_1+R_2+R_3+R_4$$

$$= \mathbf{R_{int}} + \frac{1}{2\pi(Kf-Km)} \times \left[\frac{1}{2u} \times \log\left|\frac{u+r}{u-r}\right|\right]$$

3.3 MATERIALS:

(a)Matrix Material:

Epoxy is found in both liquid and solid form. Epoxy is formed by step growth polymerisation reaction between biphenol and epichlorohydrin. Thermal conductivity of epoxy alone is very low (0.363W/m. K).

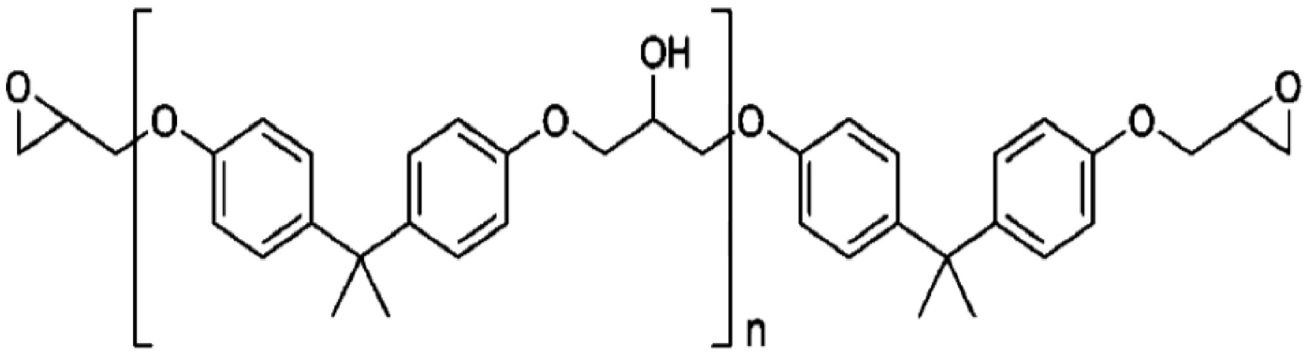


Fig 3.3: Unmodified epoxy pre polymer resin chain.

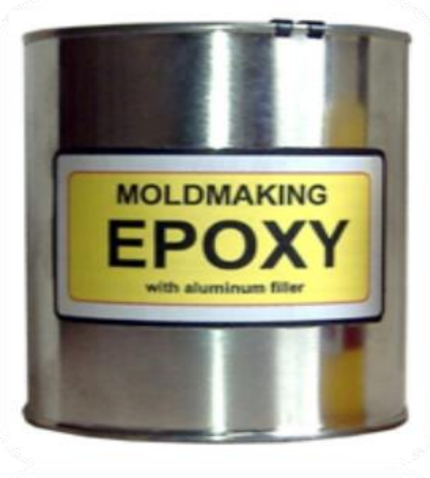


Figure 3.4 Epoxy resin and hardener

b)Filler material:-

Aluminium Nitride (AlN) is a unique ceramic material that combines high thermal conductivity with high electrical resistivity. "Thermal conductivity" is the ability of a material to transfer heat on application of a temperature gradient across its surfaces. In ceramic powder like AlN, heat transfer is through lattice vibrations in micro level. For heat dissipation applications, a high thermal conductive particle is needed to be reinforced with polymer material. The actual thermal conductivity of a material is affected by factors that reduce the propagation of lattice vibration. Temperature distribution, impurities, particle size and distribution, grain size makes it a highly usable filler material for electronic application.

COMPOSITE FABRICATION (HAND-LAY-UP TECHNIQUE):

A very simple of composite processing called Hand lay-up technique has been used to prepare physical model. The processing steps are very simple.

- Firstly, a mould release spray (heavy duty silicon spray) is sprayed on inner surface of mould in order to prevent sticking of composite to the surface.
- Appropriate amount of epoxy and AlN powder was weighted on weighting machine carefully.
- Weighted epoxy and AlN were mixed together into mould and then required amount of hardener was added drop by drop.

- Composite having two different volume fraction 15% and 26.18% of filler were prepared.
- After uniform mixing mould was left at room temperature for next 24 hour after which mould were broken and composite were taken out.

TABLE 3.1
Set up for Epoxy-TiO_2 composites

SAMPLES	COMPOSITION
1	Epoxy + 0 vol% (0 wt %) Filler
2	Epoxy + 15 vol% (32wt %) Filler
3	Epoxy + 26.18 vol% (48.6 wt %) Filler

Fabrication process using hand lay-up technique for particulate filled epoxy composites is given in Figure 3.5 showing usage of silicon spray before the mixing of composition and hardener to solidify the composite. Schematic diagram shown here

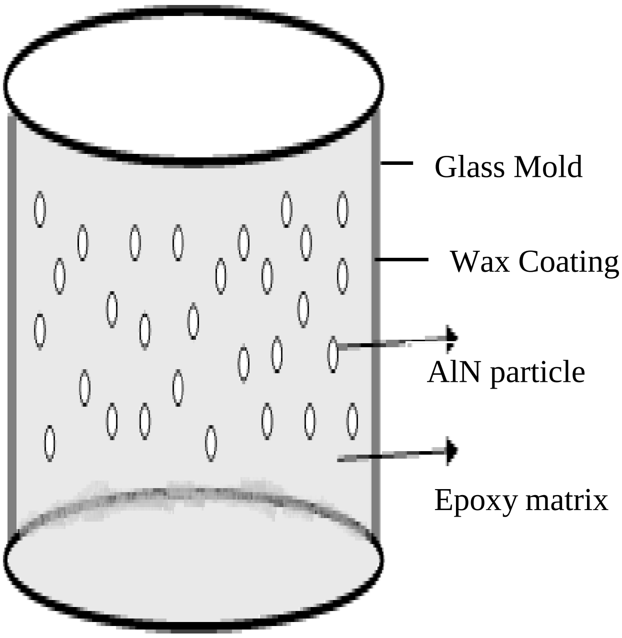


Figure 3.5 Particulate filled epoxy composite fabrication by hand lay-up process

Fabrication of composite by hand-lay-up method

Effective thermal conductivity measurement of composite was done using Unitherm^{TM} model 2022 tester. **ASTME-1530** standard is followed for this measurement.

Operating principle of Unitherm-TM 2022:

Test sample is held between two polished surfaced and compressive force applied to avoid any layer of air at interfaces. Temperatures different is applied across the test specimen. Heat flows from top, passes through the length of sample to bottom, and hence a temperature gradient is established along the length of the test specimen. Once the steady state is achieved temperature drop across the test sample is measured by temperature sensor. Thermal conductivity is then obtained using following expressions.

Fig. 3.6 Determination of Thermal Conductivity Using Unitherm™ Model 2022

For one-dimension heat flow, the equation is given as:

$$Q = \kappa A \frac{T_1 - T_2}{x}$$

The thermal resistance of the sample is given as:

$$R = \frac{T_1 - T_2}{QA}$$

From the former equation, we can write

$$k = \frac{x}{R}$$

In Unitherm^{TM} 2022, temperature difference is measured in the transducer along the upper side and lower side of the machine and the heat flux Q. This how thermal resistance can be evaluated providing thickness of different size. The thermal conductivity of the samples can be calculated using that value of thickness as input parameter and the cross sectional area as required.

Chapter Summary:

This chapter has provided:

1. The description of materials (matrix and fillers) used in this research
2. The details of fabrication of the composites
3. The details of thermal property measurement

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Chapter 4

RESULTS AND DISCUSSIONS

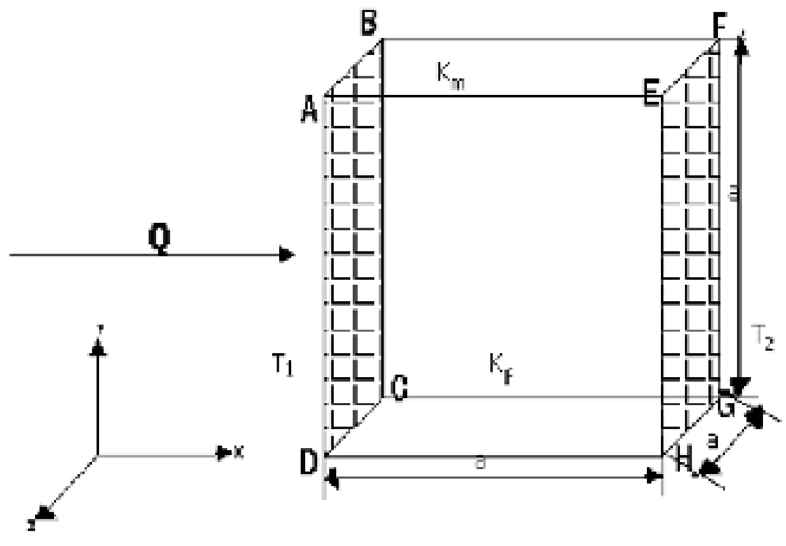
RESULTS AND DISCUSSION:

This chapter presents the results of model analysis. Effective thermal conductivity of epoxy-AlN composite obtained from theoretical model analysis and that obtained from conducted experiment is shown here. Further difference between the results obtained from both above method will be discussed and we will try to find out causes of this difference.

4.1 EFFECTIVE THERMAL CONDUCTIVITY (K_{eff}) OF ALUMINIUM NITRIDE FILLED WITH EPOXY MATRIX COMPOSITES:

Description of the problem:

Effective thermal conductivity estimation is very much important for the application of composite materials and applications in design model. The effective properties of the composites can be affected by structures of composites.



Boundary
conditions (fig 4.1)

METHODOLOGY AND MODEL DEVELOPMENT :

Development of theoretical model-

A particulate filled composite cube is shown in Figure 4.2 in 3-d model and a single element is taken under experiment for further study the heat transfer behavior as shown in Figure 4.3 compromising of the part of the matrix as a cube filled with a single spherical filler particle. The analysis carried out theoretically of the heat transfer in such a composite is based on the same assumptions that are taken for numerical analysis.

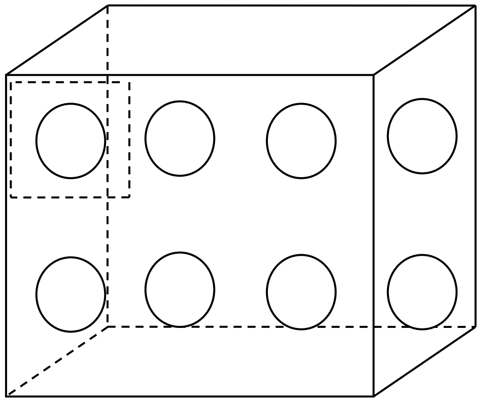


Figure 4.2 3-D view of spherical particulate filled composite cube

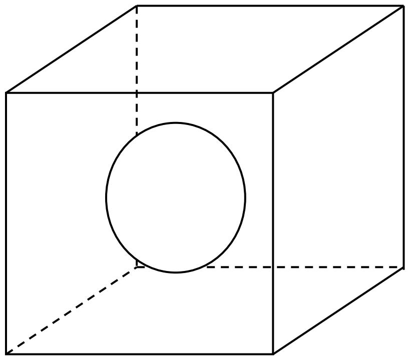


Figure 4.3 3-D view of single element under study filled in cube

CASE 1

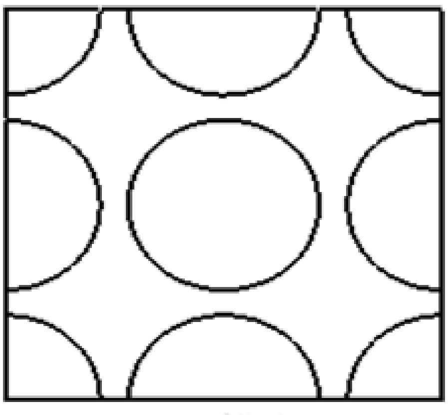


FIG 4.4

$$0.15 \times a^3 = 4 \times \frac{4}{3} \times \pi r^3$$

so, **a= 4.6r**

An analytical model is taken considering a cube of matrix with side H and it is embedded with spherical particles with radius R. When we consider a system or model in which only conduction is the only way to transfer heat, then we have to construct a thermal circuit in which sum of all resistances in small elements in the model is taken to be the total resistances of entire model. There are such combinations of small particles inside the cube. So thermal properties of the body depends on how heat is transferred within the cube embedded in those small elements.

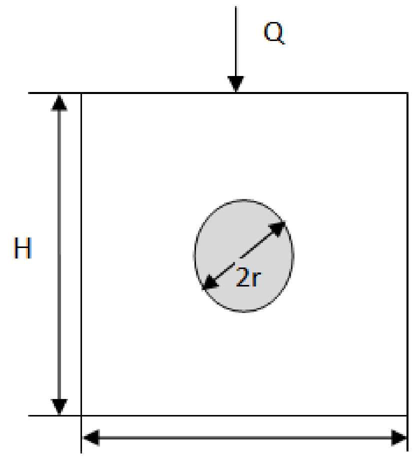


Figure 4.5 Physical model of heat transfer

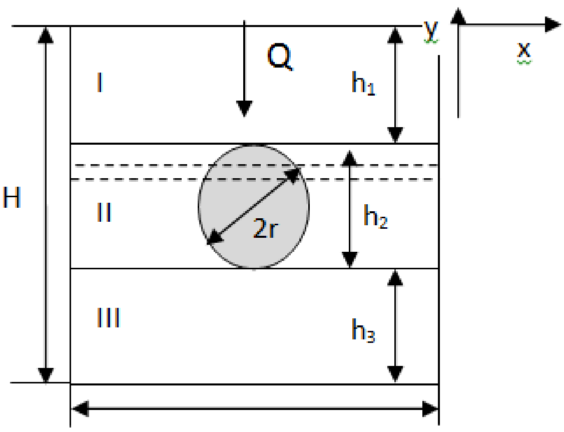


Figure 4.6.Series model of heat transfer

Take a strip of the particulate sphere with thickness dy

Then radius of the strip = $\sqrt{r^2 - y^2}$

Area of the filler =A_f = $2\pi\sqrt{r^2 - y^2}$

Area of the matrix = A_m =$a^2 - 2\pi\sqrt{r^2 - y^2}$

K_f and K_m are conductivies of filler and matrix material respectively

R_f= thermal resistance of filler $=\dfrac{dy}{Kf\times 2\pi(r^2-y^2)}$

R_m=thermal resistance of matrix $=\dfrac{dy}{Km(a^2-2\pi(r^2-y^2)}$

It is assumed to be a parallel connection

$$Rtotal^{-1} = Rf^{-1} + Rm^{-1}$$

$$\mathbf{R_{total}} = \frac{Kf\times 2\pi(r^2-y^2)}{dy} + \frac{Km(a^2-2\pi(r^2-y^2)}{dy}$$

$$=\int_0^r \frac{dy}{2\pi(Kf-Km)\left\{r^2+\frac{Kma^2}{2\pi(Kf-Km)}-y^2\right\}}$$

$$\mathbf{R_{total}}=\int_0^r \frac{dy}{2\pi(Kf-Km)(u^2-y^2)}$$

$$\textbf{Where } \mathbf{u} = \sqrt{r^2+\frac{Km\times a^2}{2\pi(Kf-Km)}}$$

Integrating R_{total} from 0 to r

$$R_{tota}= \int_0^r \frac{dy}{2\pi(Kf-Km)(u^2-y^2)}$$

$$= \frac{1}{2\pi(Kf-Km)} \times \left[\log\left|\frac{u+y}{u-y}\right|\right]$$

$$= \frac{1}{2\pi(Kf-Km)\times 2u} \times \left[\log\left|\frac{u+r}{u-r}\right|\right]=R_1=R_2=R_4=R_6$$

$$R_2=R_5=\frac{a-4r}{2Km\times a^2}$$

CASE- 2 :-

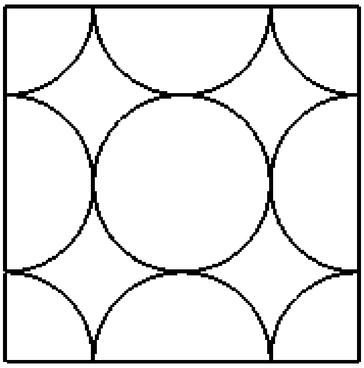


FIG 4.7

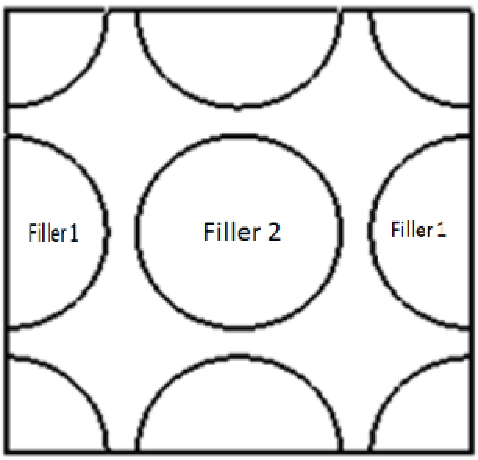
In this case , particulates are arranged in such a manner that there is no gap between the layers of particulates.

Here the volume fraction is equal to 26.18 %

Hence we take a= 4r

Here we can use similar expression of R_{total} as derived in earlier case . But with a slight diffrence that . here $R_{contact}$ =0 , because the layer of matrix witout particulate is not there.

- $R_{total}=\frac{1}{\pi(Kf-Km)\times u}\log\left|\frac{u+r}{u-r}\right|$



CASE 3 FIG 4.8

In this matrix is filled with two different fillers (filler 1 & filler 2) having thermal conductivities K_{f1} and K_{f2}

Here the volume fraction is less than 26.18 % . Derivation is similar to the case 1.

FOR FILLER 1

Thermal resistance $R_{f1} = \dfrac{dy}{Kf1(\pi(r^2-y^2)}$

FOR FILLER 2

Thermal resistance $R_{f2} = \dfrac{dy}{Kf2(\pi(r^2-y^2)}$

Thermal resistance of the matrix $R_m = \dfrac{dy}{Km(a^2-2\pi(r^2-y^2)}$

All are connected in parallel arrangement

$$\mathbf{R_{total}^{-1}=R_{f1}^{-1}+R_{f2}^{-1}+R_m^{-1}}$$

$$= \frac{dy}{Kf1(\pi(r^2-y^2)}^{-1} + \frac{dy}{Kf2(\pi(r^2-y^2)}^{-1} + \frac{dy}{Km(a^2-2\pi(r^2-y^2)}^{-1}$$

$$\mathbf{dR_{total}} = \frac{dy}{\pi(Kf1+Kf2-2Km)(r^2-y^2)+Km\times a^2}$$

$$= \frac{dy}{\pi(Kf1+Kf2-2Km)(u^2-y^2)} + d\mathbf{R_{contact}}$$

Where $u = \sqrt{\dfrac{Km\times a^2}{Kf1+Kf2-2Km} + r^2}$

$$\mathbf{R_{total}} = \int_0^r \frac{dy}{\pi(Kf1+Kf2-2Km)(u^2-y^2)} + \mathbf{R_{contact}}$$

$$= \frac{dy}{2\pi(Kf1+Kf2-2Km)u} \log\left|\frac{u+r}{u-r}\right| + \mathbf{R_{contact}}$$

At all the cases $\mathbf{K_{eff}} = \frac{1}{Rtotal \times a}$ Where a = side of the cube (matrix)

4.1.2 Numerical Analysis

Here an ANSYS analysis is shown evaluating the temperature distribution of aluminium nitride filled epoxy composite in static thermal model. By taking different arrangemts of fillers in terms of volume fraction and assuming certain temperature along the side of the matric cube meshing is done. The heat flow is assumed to be uniform along the selected faces. Final model of temperature distribution is shown below.

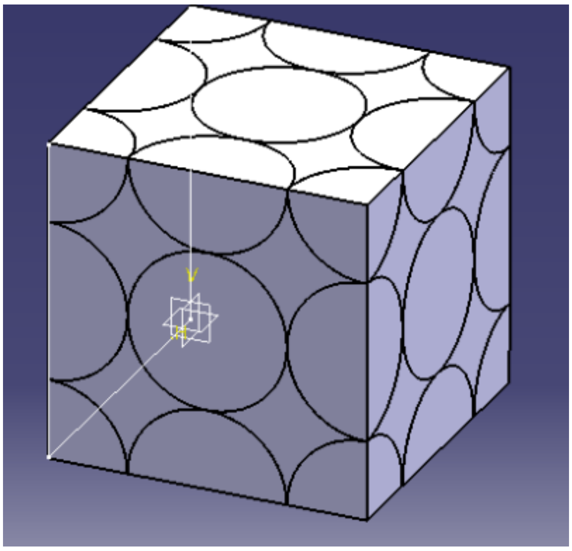


FIG 4.9

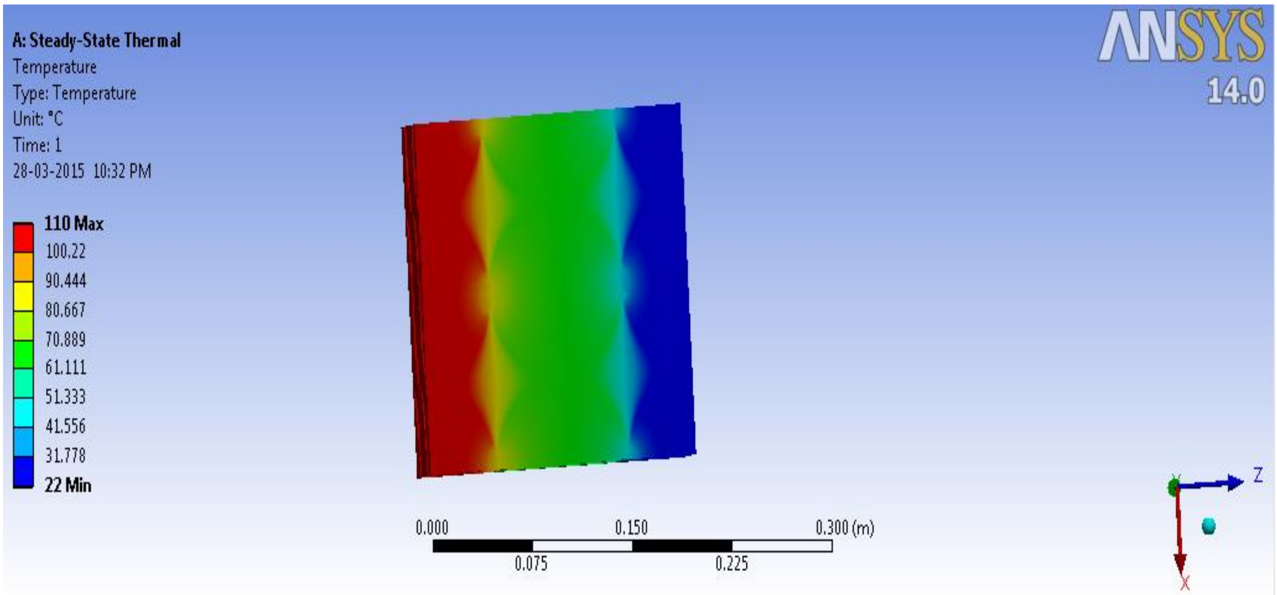


FIG 4.10

This is the analytical and ANSYS model of a epoxy cube filled with Aluminium

Nitride particulate.

Volume fraction here is 26.18 %. Above shows the thermal distribution of epox composite with 26.18 % vol. fraction.

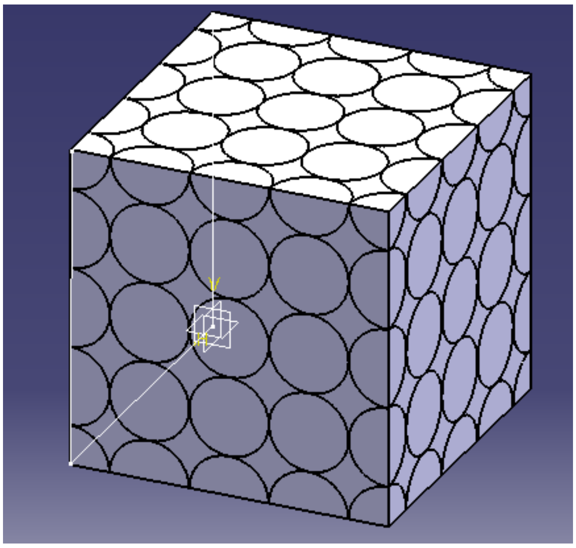


FIG 4.11

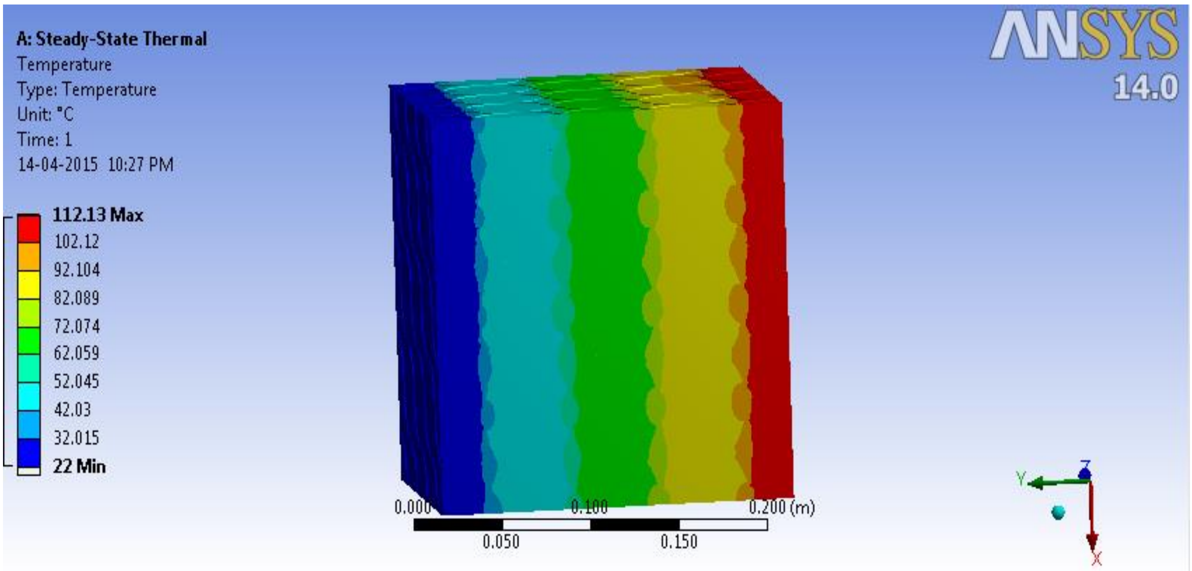


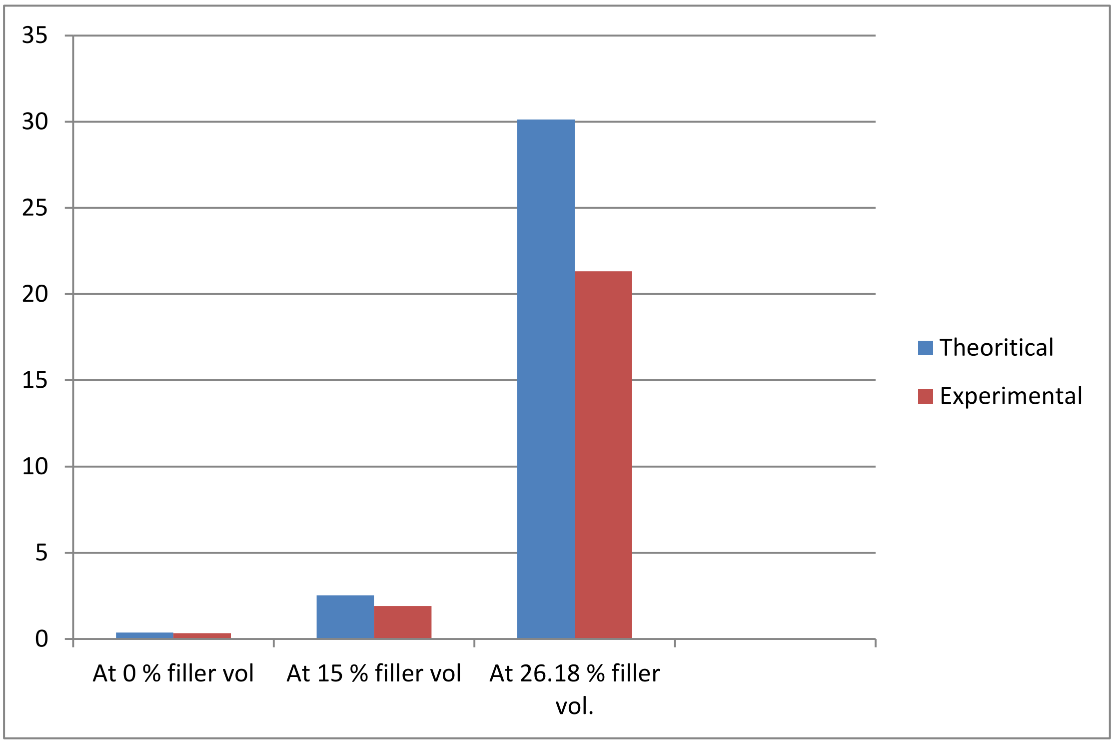
FIG 4.12

Temperature distribution of epoxy composite filled with particulate at 32.72 % volume fraction. Effective thermal conductivity for polymer composite filled with particulates is found out for different volume fractions. It is found that K_{eff} can be expressed as a function of fraction of filler content in the composite (**Ø**), thermal conductivity of filler material (**K_f**) and thermal conductivity of matrix material (**K_m**).

$$K_{eff} = f(Ø, K_f, K_m)$$

TABLE 4.1 COMPARISON OF THERMAL CONDUCTIVITY BY ANALYTICAL METHOD RESPECT TO EXPERIMENTAL METHOD

SAMPLE NO.	VOL % OF AlN	K_{eff} by analytical	K_{eff} by experiment	Error %
1	0	0.363	0.34	6.7
2	15	2.53	1.92	31
3	26.18	30.83	21.33	44.7



OBERVATIONS TO BE NOTICED:

There is a sharp increase in effective thermal conductivity of composite when volume fraction of particulate is 26.18 %. This sharp enhancement in thermal conductivity can be explained by the fact that after 26.18% volume fraction of particulate in matrix material, particulates start overlapping with each other which lead to the formation of conductive chain in the direction of heat flow which eventually results in sharp enhancement in thermal conductivity. There is a significant difference in result obtained from analytical modelling and that obtained from experimental measurement. This difference is due to the fact that we neglected the interfacial resistance between the contact surfaces of particulate and matrix material. This difference is also evident that interfacial resistance have significant contribution in total thermal resistance and hence cannot be safely neglected.

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Chapter 5

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS AND SCOPE FOR FUTURE WORK

5.1 Conclusions

Following conclusion has been drawn from theoretical analysis and experimental investigation.

1. Successful manufacturing of ALUMINIUM NITRIDE filled epoxy polymer composite is possible by conventional Hand - layup method can be possible.

2. The expressions which have been developed in present work can be used to determine the effective thermal conductivity of composite material with different volume fractions.

3. The magnitude of effective thermal conductivity obtained from analytical model and that obtained from experimental investigation for various volume fractions are under agreement for volume percentage of particulate ranging from 0 to 26.18%.

4. Inclusion of AlN powder in epoxy polymer composite results in substantial increase in effective thermal conductivity of epoxy-AlN composite. For inclusion of 15 % of AlN by volume, effective thermal conductivity rises by 5 times. Similarly with the inclusion of 26.18 % of AlN by volume, corresponding increment in the effective thermal conductivity is found by 59 times.

5. This new developed epoxy-AlN composite can be employed for various applications like electronic packaging, glob top encapsulation, printed circuit board etc.

5.2 Scope for future work

This work provides a good area of interest for future investigations to explore thermal behaviour of particulate filled polymer composites in many other aspects. Also, effect of volume fraction of particulate has been studied theoretically and experimentally. Apart from volume fraction there are other parameters which can affect the thermal conductivity positively, such as

1. Effect of size and shape of particulate can be investigated.

2. Exploration of various new fillers for the development of materials which are thermally more conductive as well as with low cost.

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